THE LEP PROJECT - STATUS REPORT

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Introduction

LEP is an e^+e^- collider ring designed and optimized for 2 x 100 GeV. In an initial phase an energy of 2 x 55 GeV will be reached by using copper acceleration cavities. The upgrading to the design energy will be done in stages using superconducting cavities which are in an advanced stage of development. The same frequency of 352 MHz has been chosen for both kinds of cavities, which allows the use of the same klystrons, wave guides, etc. for the upgrading (for more information on the s.c. cavities see talk of H. Lengeler).

The optimization for about 100 GeV per beam gave a bending radius of approximately 3.5 km. For the rf cavities and the experiments 8 straight sections are foreseen which bring the total circumference to close to 27 km (see Fig. 1). Hence LEP is the largest accelerator under construction. Indeed it is its size, its underground location with only 8 access points and the large number of components, which presents the major challenge of this project.

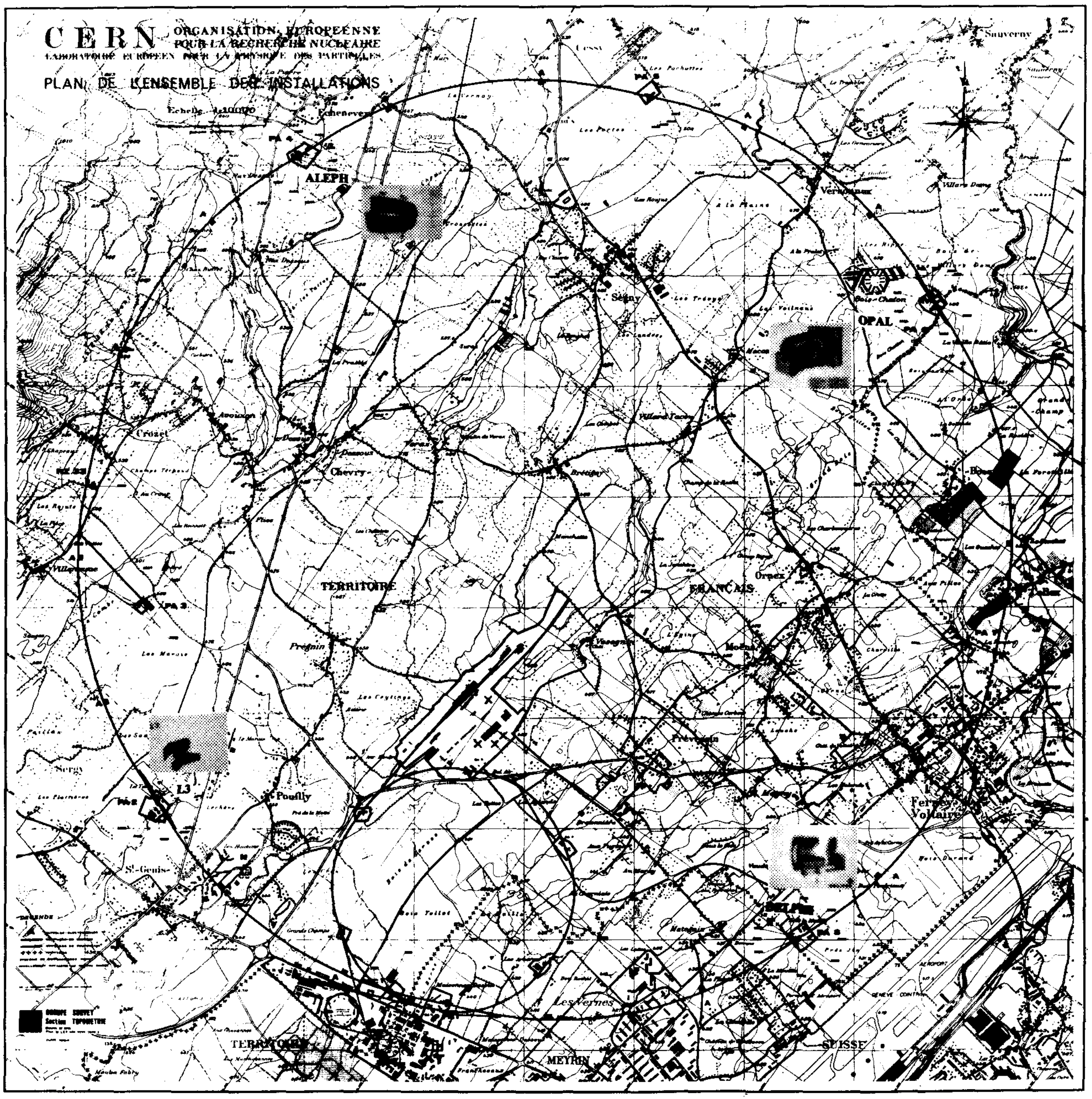

Fig. 1 Plan of LEP
4 Experimental facilities will be installed in the straight sections 2, 4, 6 and 8.
The accelerating cavities will be located in the straight sections 2 and 6 for LEP phase 1.

Since the tunnel and the associated infrastructure represent a major effort, emphasis was given already at the ti of a 1 t rovi e ur er options afte LEP. Therefore the tunnel diameter was made as large as possible, taking account of geological and other limitations, and also the tunnel cross section and the LEP magnet position as chosen in such a way as to allow the installation of a hadron ring on top of the LEP ring. The various options for a hadron collider in the LEP Tunnel (LHC) or a e-p collider will be described later by G. Brianti.

LEP was approved in December 1981 and the investment cost at current prices is somewhat above 1 Billion Swiss Francs. Contracts for about 90% of this have been placed. It is the first time that such a big project has had to be built within the existing constant budget and with a slightly diminishing staff. Many other activities at CERN had therefore to be reduced or even terminated.

Apart from some unforeseen, mainly geological contingencies the project is within a few percent of the approved budget, and it is planned to start the machine and the experiments early in 1989.

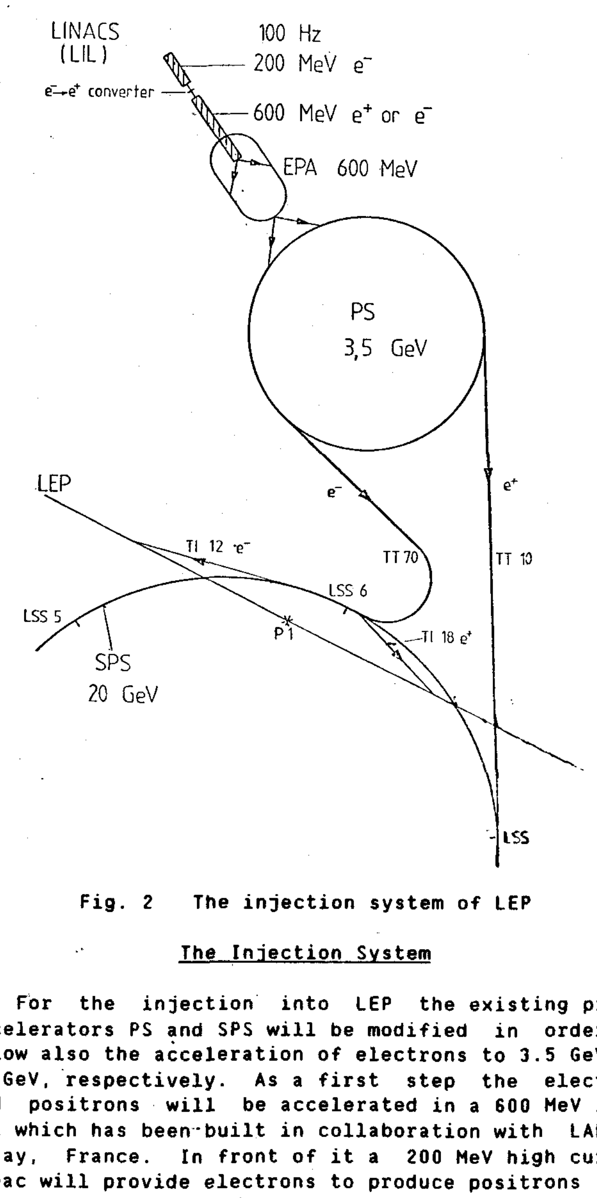

Fig. 2 The injection system of LEP

The Injection System

For the injection into LEP the existing proton accelerators PS and SPS will be modified in order to allow also the acceleration of electrons to 3.5 GeV and 20 GeV, respectively. As a first step the electrons and positrons will be accelerated in a 600 MeV linac LIL which has been built in collaboration with LAL at Orsay, France. In front of it a 200 MeV high current linac will provide electrons to produce positrons (see Fig. 2). Electrons and positrons will be accumulated in a little storage ring EPA in 8 bunches (see Fig. 3).

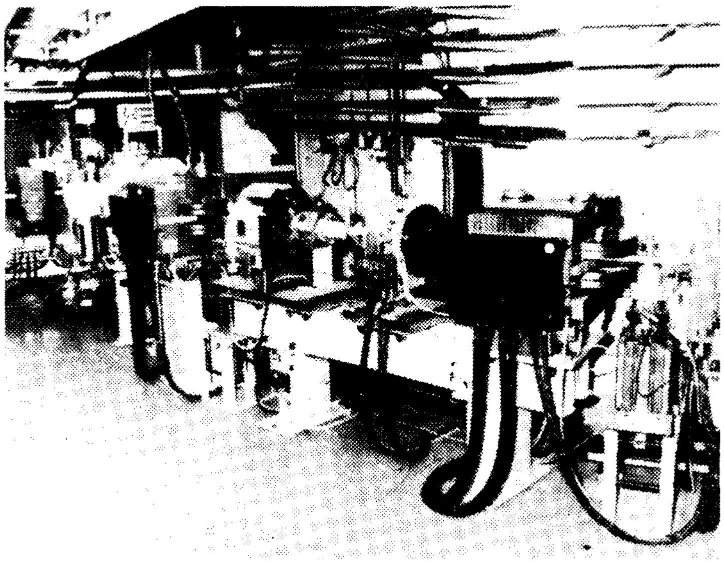

Fig. 3 The accumulator ring EPA which has started operation

LIL has started operation in spring 1986 and also EPA was recently commissioned. Almost immediately 100 mA were obtained in the 8 bunches of EPA (compared to the design value of 72 mA) and 4.5×10^{10} electrons in a single bunch, which is two times more than needed. The extraction of electrons from EPA has also been successfully tested. After tuning up of the whole system, injection studies into the PS will start by September 1986.

The modification of the PS and SPS is well under way. It is foreseen to interleave the relatively short acceleration cycles for electrons and positrons with those for proton acceleration. In this way filling of LEP and proton fixed target physics can go on simultanously.

Main Ring Components

The present period is characterized by the arrival of large numbers of components which have to be prepared for the installation in the tunnel.

Magnets

In order to reduce the synchrotron radiation losses the circumference has to be covered as smoothly as possible with magnets. The dipole magnets were designed up to a field corresponding to an energy of 125 GeV, but even there a field of only 0.135 Tesla is required. In order to keep the cost low a new type of magnet was developped. The yokes consist of steel laminations which are spaced about 0.5 cm apart. The space in b t i f ll d th t i d t d th necessary mechanical stability. 3360 of these "concrete magnets" are needed. About 60% of them have already been delivered to CERN by two different civil engineering firms (see Fig. 4). Two of these dipole magnets are assembled with the vacuum chamber into a complete unit which can be lowered down into the tunnel in order to speed up the installation.

The dipole magnets do not have a proper coil, but they will be excited by 4 aluminium bars which essentially run around the whole ring. 18 km of these bars have been delivered.

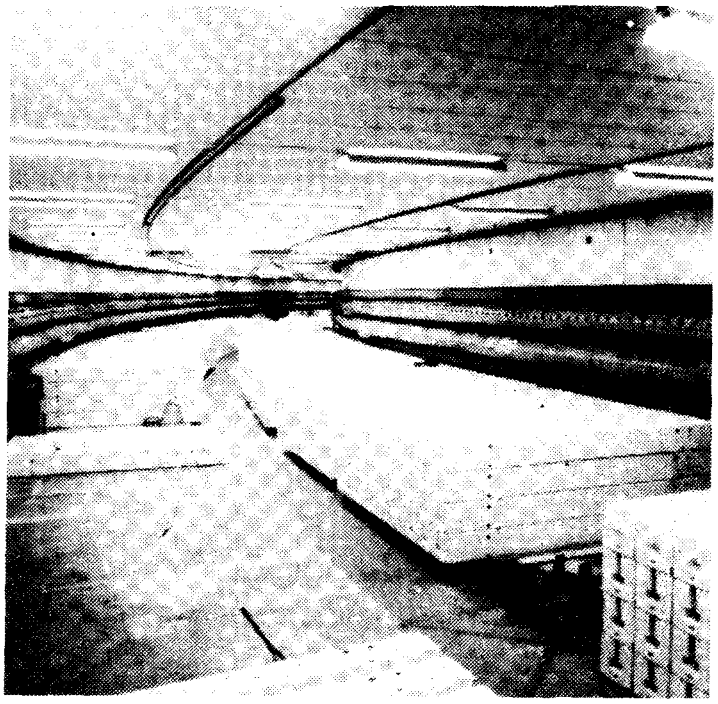

Fig. 4 "Concrete" dipole cores stored in the ISR tunnel

In total 814 quadrupoles are required of which about 30% have been delivered (see Fig. 5). Of the 508 sextupoles needed about 50% are already at CERN.

Fig. 5 Part of the quadrupoles already delivered to CERN

Accelerating System

The rf accelerating cavities will be installed in stages. For the first phase of LEP copper cavities will be used. A new idea will permit the reduction of the power consumption. Because of the large size of LEP the time between 2 bunches crossing a cavitiy is relatively long (~ 22 µs). To maintain the accelerating field all the time would lead to unnecessary losses and hence a low- loss storage cavity is coupled to each accelerating cavity. The coupling of these two resonators is arranged in such a way that the full accelerating field is built up in the accelerating cavity when the bunch is there, whereas for most of the rest of the time the rf energy is stored in the low-loss cavity. 16 cavities are grouped together and are fed by 2 klystrons. These deliver 1 MW power in CW operation at an efficiency of about 65%. They have been developed by two European firms. 8 such units will be installed in the straight sections 2 and 6 requiring in total 128 cavities and storage cavities.

90 of these units (cavity plus storage cavity) have been delivered and 9 of the 16 klystrons required are already at CERN. The delivery of other parts, e.g. tuners, couplers, wave guides, is far advanced. A full rf unit (16 cavities, 2 klystrons) has been set-up in a make-up tunnel at the surface in order to test the equipment and to practise the installation in the tunnel.

Vacuum System

The vacuum chamber is fabricated from extruded aluminium. In the dipole magnets it has a side chamber for a getter pump which has to absorb the gases released from the vacuum chamber by the synchrotron radiation. Since the dipole fields are so low the fringe field cannot be used for the getter pumps. For this reason a new pumping material was developed which does not require a magnetic field. These NEG (non-evaporable getter pump) strips were tested extensively and their pum ing spee s a e about 3 imes better t the original specifications. About 500 chambers for dipoles and 300 for quadrupoles have been delivered. More than 16 km of NEG strips are already at CERN.

The vacuum chambers have to be cladded by lead in order to absorb the synchrotron radiation. A new method has been applied for this cladding procedure and about 330 chambers are already cla e.

The delivery of all the auxiliary equipment (sputter pumps, roughing pumps, etc.) is far advanced.

Testing and baking of the chambers is going on (see Fig. 6). Two dipole magnets with one common vacuum chamber will be assembled into one unit at the surface which will be lowered down into the tunnel for fast installation.

Fig. 6 Vacuum chambers under test

Beam Instrumentation and Controls

Beam position and current measuring devices have been designed and their production is well under way. As in most other areas it is the size of LEP and the large number of components which provide the major challenge.

The architecture of the control system has been developed and components are being ordered from industry. It was decided that LEP will be operated from the same control room as the SPS and hence the two control systems have to be compatible. By modernizing the SPS system the two systems will eventually become similar, both using local area ring networks instead of the previous star networks.

Other components

The delivery and installation of many other components is proceeding well. Special efforts have to be made for the infrastructure, e.g. power converters and cables, signal cables, cooling and ventilation. Again a major challenge is given by the long distances involved (10 km across the ring!) and by the few access points.

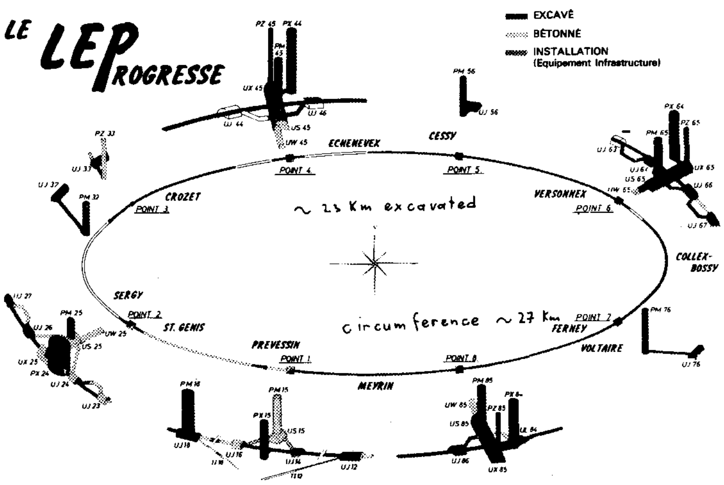

Fig. 7 Present state of excavation

Civil Engineering

Impressive progress has been made by the two consortia of firms which are digging the tunnel. At the time of this report about 23 of 26,7 km have been excavated. A few hundred metres remain on both sides of point 4 which are critical because of a geological fault, and about 3 km between point 2 and 3 (see Fig. 7). A few geological difficulties were encountered but no serious problem has been met so far. It should be remembered that the tunnel itself presents only about half of the total volume to be excavated since the 18 access shafts and in particular the large caverns for the experiments correspond to a comparable volume. All these shafts and caverns are fully excavated (see Fig. 8). All the excavation work should be terminated by the end of 1986 if no geological problems are met. After the tunnel has been completed the detailed planning for the installation of the machine and the experiments will be up-dated.

The octant between point 1 and 2 has been lined with concrete and has been handed over for installation (see Fig. 9). Also for some caverns and shafts the concrete lining has been finished.

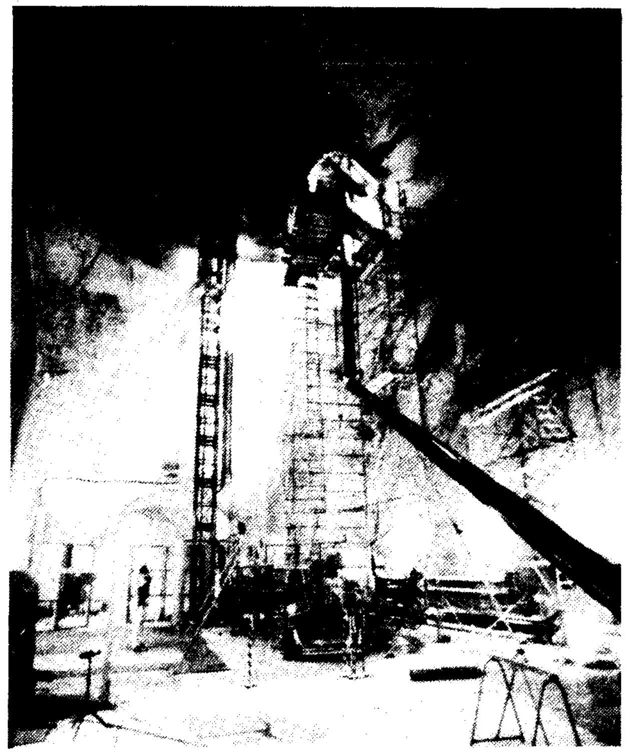

Fig. 8 One of the experimental caves

The installation of the infrastructure (lighting, ventilation, water, etc.) has started. In order to equip the shafts with elevators, stair cases, ducts for ventilation and cables, a new method has been developed which relies on prefabricated modules. One shaft has been installed already in this way and the feasibility of this method has been proven.

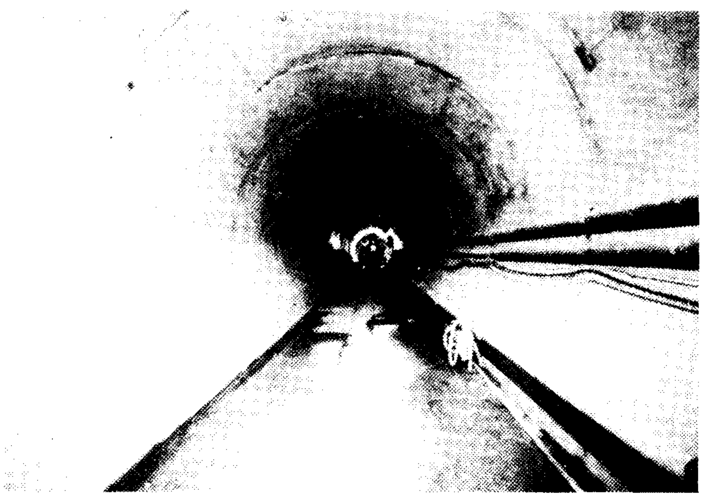

Fig. 9 Part of the LEP tunnel

A monorail train hanging from the ceiling will be the main means of tranport in the tunnel. Extensive tests at a surface installation have been carried out with this system and different elements like driving cabins have already arrived at CERN in large numbers (see Fig. 10).

About 70 surface buildings surrounding the access shafts are needed to house different services e.g. cranes, power supplies, ventilation, gases. The construction of these buildings is in full progress and about 1/3 has been finished already.

Fig. 10 Diverse cabines for the monorail trains

Experimental Facilities

Four large detectors have been approved (ALEPH, DELPHI, L3 and OPAL). They are being constructed involving about 1200 physicists from Europe, USA, Japan, USSR, China, and other countries.

The preparation of these facilities is progressing very well and all four will be ready for the first collisions in LEP at the beginning of 1989. The fabrication of the large components, e.g. magnet yokes, magnet coils (2 experiments use superconducting coils which are built by Saclay and RAL, respectively), central track detectors, electromagnetic and hadron calorimeters, is well advanced and some have already arrived at CERN (see Fig. 11).

The total investment cost for all 4 facilities is aobut 460 MSF, that is about half the cost of LEP. Indeed each of the detectors corresponds to a project of a medium size accelerator. We were faced with a completely new situation in that the main resources are not provided by CERN but by outside Laboratories. The overall breakdown gives a contribution of 39% from Laboratories in CERN Member-States, 34% from non-Member States, and 27% from CERN. Some people thought that it would be impossible to realize such big projects without direct control. In order to monitor the construction of the detectors both from the technical and financial point of view special management structures have been created. So far all major problems could be overcome and the detectors should be ready at the turn-on of LEP although some parts will have to be staged because of financial difficulties.

The interest in LEP physics is still increasing, not only for the first stage with centre-of-mass energies in the range 100 to 120 GeV, but a Workshop will take place in fall 1986 to discuss the physics and the potentialities of the detectors for energies up to 200 GeV centre-of-mass energy.

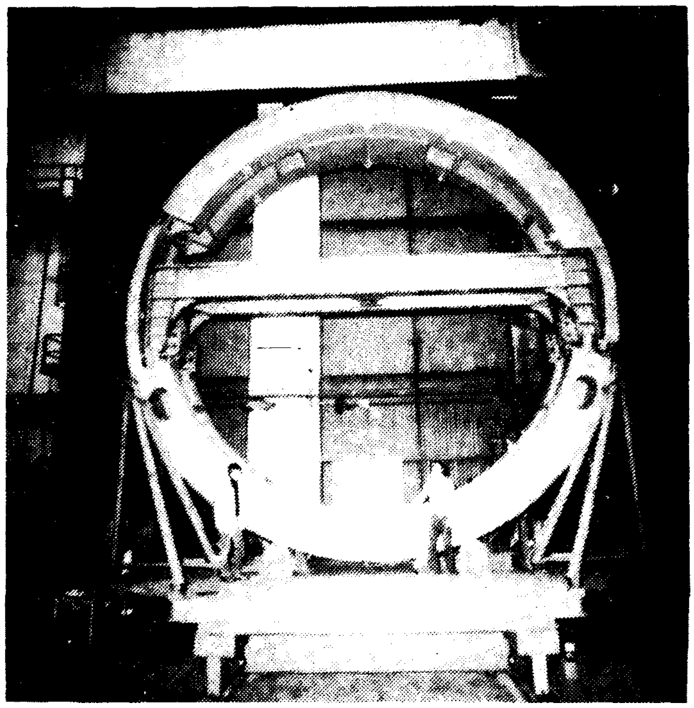

Fig. 11 Support structure for the lead glass calorimeter of OPAL

Discussion

I.Nishikawa. Can you give me some figures of the operating sum money for the experimental apparatus compared to that of accelerator?

H.Schopper. Large part of the operating money goes into power. The total operating money when LEP is not stopped - not operating through the whole year but we count that until 1989 it will only operate part of the year. When it comes into full operation the operating cost will be of the order of 60 to 70 million Swiss francs or 30-40 million dollars. For the experiment we think, each experiment will lead ... Well, it depends on how you define operating cost. Excluding power, I think, just gases, replaces, repair of electronics and so on - of the order of 2 to 3 million dollars.